

The recent Higgs boson data and Higgs triplet model with vectorlike quarks

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Abstract

Some vectorlike quarks are added to the Higgs triplet model with the motivation of fitting the recent Higgs boson data released by LHC and Tevatron collaborations. These vector-like quarks can suppress the cross section of $gg \rightarrow h$ sizably, while the charged scalars, especially for the doubly charged scalar, can enhance $Br(h \rightarrow \gamma\gamma)$ more sizably. Besides, the Higgs couplings to WW , ZZ and light fermions can be the same as their SM values. Thus, the model will enhance the Higgs production rates into $\gamma\gamma$ and $jj\gamma\gamma$, while those for WW^* , ZZ^* and $\tau\bar{\tau}$ at the LHC are reduced relative to their SM predictions. The Higgs production rate into $Vb\bar{b}$ at the Tevatron is the same as the SM prediction.

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I. INTRODUCTION

The hint of a Higgs particle around 125 GeV revealed earlier by the ATLAS and CMS experiments [1–4], has now become an indisputable discovery [5], which is supported by the data from the Tevatron collider experiments [6]. Although the present results of all the search channels have large uncertainty, all measured $\gamma\gamma$ rates have central values above the standard model (SM) prediction, and all the WW^* rates have central values below the SM prediction [5, 7–9]. The observation of the channel $q\bar{q} \rightarrow Vh$ with $h \rightarrow b\bar{b}$ at the Tevatron disfavors the scenarios in which the Higgs couplings to gauge bosons and bottom quarks are significantly reduced with respect to their SM values [10]. Ref. [11] performed a phenomenological fit to the new ATLAS, CMS, CDF and D0 Higgs boson data, and found that the present data favor a reduction of $gg \rightarrow h$ rate and an enhancement of $h \rightarrow \gamma\gamma$ rate.

In this paper, we introduce some vector-like quarks in the framework of Higgs triplet model (HTM) with the motivation of obtaining a Higgs boson with the properties mentioned above. The HTM which we will study contains a complex doublet Higgs field and a complex triplet Higgs field with hypercharge $Y = 2$ [12]. Several physical Higgs bosons remain after the spontaneous symmetry breaking, including two CP-even (h and H), one CP-odd (A), one charged (H^\pm) and one doubly charged Higgs scalars ($H^{\pm\pm}$). We will take h as a purely SM-like Higgs with around 125 GeV mass, and its couplings to WW , ZZ and light fermions nearly equal to their SM values, which can fit the $Vb\bar{b}$ rate measured at the Tevatron relatively well. The rate of $gg \rightarrow h$ is sizably suppressed by the vector-like quarks while the $Br(h \rightarrow \gamma\gamma)$ is more sizably enhanced by the singly and doubly charged scalars. The LHC Higgs diphoton signal has been studied in the original HTM [13, 14]. The recent Higgs data has been discussed in various extensions of the SM, such as the minimal supersymmetric standard model (MSSM) [15], the next-to-MSSM [16], the inert Higgs doublet model [17], the two Higgs doublet model [18, 19], the little Higgs models [20], the models with extra dimension [21] and the models with the universal varying Yukawa couplings [22].

This work is organized as follows. In Sec. II, we briefly review the Higgs triplet model and then introduce some vector-like quarks. In Sec. III, we discuss the $gg \rightarrow h$ rate and branching ratio of $h \rightarrow \gamma\gamma$. In Sec. IV, we calculate the Higgs production rates at the LHC and Tevatron. Finally, we give our conclusion in Sec. V.

II. THE HIGGS TRIPLET MODEL WITH VECTOR-LIKE QUARK

In the HTM, a complex $SU(2)_L$ triplet scalar field Δ with $Y = 2$ is added to the SM Lagrangian in addition to the doublet field Φ . These fields can be written as

$$\Delta = \begin{pmatrix} \delta^+/\sqrt{2} & \delta^{++} \\ \delta^0 & -\delta^+/\sqrt{2} \end{pmatrix}, \quad \Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}. \quad (1)$$

The renormalizable scalar potential can be written as

$$\begin{aligned} V = & -m_\Phi^2 \Phi^\dagger \Phi + \frac{\lambda}{4} (\Phi^\dagger \Phi)^2 + M_\Delta^2 \text{Tr}(\Delta^\dagger \Delta) + \lambda_1 (\Phi^\dagger \Phi) \text{Tr}(\Delta^\dagger \Delta) \\ & + \lambda_2 (\text{Tr} \Delta^\dagger \Delta)^2 + \lambda_3 \text{Tr}(\Delta^\dagger \Delta)^2 + \lambda_4 \Phi^\dagger \Delta \Delta^\dagger \Phi + [\mu (\Phi^T i \tau_2 \Delta^\dagger \Phi) + h.c.]. \end{aligned} \quad (2)$$

The Higgs doublet and triplet field can acquire vacuum expectation values

$$\langle \Phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_d \end{pmatrix}, \quad \langle \Delta \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 \\ v_t & 0 \end{pmatrix} \quad (3)$$

with $v^2 = v_d^2 + 4v_t^2 \approx (246 \text{ GeV})^2$.

In the HTM, there are seven physical Higgs bosons, including two CP-even (h and H), one CP-odd (A), one charged (H^\pm) and one doubly charged Higgs scalars ($H^{\pm\pm}$). The scalar potential contains seven independent parameters: λ , $\lambda_{i=1\dots 4}$, μ and v_t . Since the experimental value of the ρ parameter is near unity, v_d^2/v_t^2 is required to be much smaller than unity at tree-level, which can produce naturally a very small neutrino mass for Yukawa coupling of order 1 [23]. The perturbative unitarity and potential boundedness can give strong constraints on these parameters. Refer to [13], we take

$$\begin{aligned} v_t &= \mu = 1 \text{ GeV}, & \lambda &= 0.516, & 0 < \lambda_1 < 10, \\ \lambda_3 &= 2\lambda_2 = 0.2, & -2 < \lambda_4 < 1. \end{aligned} \quad (4)$$

For such parameter space, the seven Higgs masses can be given as

$$\begin{aligned} m_h^2 &\simeq \frac{\lambda}{2} v_d^2 \simeq (125 \text{ GeV})^2, \\ m_H^2 &\simeq m_A^2 \simeq \frac{\sqrt{2} \mu v_d^2}{2v_t}, \\ m_{H^{\pm\pm}}^2 &= \frac{\sqrt{2} \mu v_d^2 - \lambda_4 v_d^2 v_t - 2\lambda_3 v_t^3}{2v_t}, \\ m_{H^\pm}^2 &= \frac{(v_d^2 + 2v_t^2)[2\sqrt{2}\mu - \lambda_4 v_t]}{4v_t} \simeq m_{H^{\pm\pm}}^2 + \frac{\lambda_4}{4} v_d^2. \end{aligned} \quad (5)$$

Where we take $\mu = v_t$ in order to make h to be a purely SM-like Higgs boson, for which the mixing of h and H is nearly absent. The cosine value of the mixing angle is always larger than 0.996 for the parameter space shown in Eq. (4). $\lambda = 0.516$ determines the mass of h to be around 125 GeV. When μ is much less than v_t , h and H have large mixing. The H can be even as a purely SM-like Higgs boson for enough small μ [13]. However, the large μ can enhance the masses of H^+ and H^{++} , which will suppress their contributions to $h \rightarrow \gamma\gamma$ sizably.

The scalar potential term in Eq. (2) contains the SM-like Higgs boson coupling to the charged scalars [13],

$$g_{hH^{++}H^{--}} \approx -\lambda_1 v_d, \quad g_{hH^+H^-} \approx -(\lambda_1 + \frac{\lambda_4}{2})v_d. \quad (6)$$

Now we add some vector-like quarks to the HTM. When a unique additional vector-like multiplet are introduced to the SM Lagrangian, the cross section of $gg \rightarrow h$ will be increased or slightly decreased relatively to the SM prediction since the physical signs of the Yukawa couplings are identical for the top quark and extra quark. Ref. [24] proposed a minimal scenario in which the cross section of $gg \rightarrow h$ can be strongly suppressed. Following the approach in ref. [24], we introduce the doublet $(q_{5/3}, t')_{L,R}^T$, the singlet t''_L and t''_R in addition to the SM-like fields. Where the L/R represents the fermion chirality and $q_{5/3}$ is an exotic quark with the electric charge 5/3. Their Yukawa interactions with the doublet Higgs field can be written as

$$\begin{aligned} \mathcal{L}_{\text{Yuk}} = & y \overline{\begin{pmatrix} t \\ b \end{pmatrix}_L} \tilde{\Phi} t_R + y' \overline{\begin{pmatrix} q_{5/3} \\ t' \end{pmatrix}_L} \Phi t_R + y'' \overline{\begin{pmatrix} q_{5/3} \\ t' \end{pmatrix}_{L/R}} \Phi t''_{R/L} + \tilde{y} \overline{\begin{pmatrix} t \\ b \end{pmatrix}_L} \tilde{\Phi} t''_R \\ & + y_b \overline{\begin{pmatrix} t \\ b \end{pmatrix}_L} \Phi b_R + m \bar{t}''_L t_R + m' \overline{\begin{pmatrix} q_{5/3} \\ t' \end{pmatrix}_L} \begin{pmatrix} q_{5/3} \\ t' \end{pmatrix}_R + m'' \bar{t}''_L t''_R + \text{h.c.}, \end{aligned} \quad (7)$$

where $\tilde{\Phi} = i\sigma_2 \Phi^*$. After EWSB takes place, the Lagrangian (7) gives rise to the top mass matrix:

$$\mathcal{L}_{\text{mass}} = \overline{\begin{pmatrix} t \\ t' \\ t'' \end{pmatrix}_L} \begin{pmatrix} yv/\sqrt{2} & 0 & \tilde{y}v/\sqrt{2} \\ y'v/\sqrt{2} & m' & y''v/\sqrt{2} \\ m & y''v/\sqrt{2} & m'' \end{pmatrix} \begin{pmatrix} t^c \\ t' \\ t'' \end{pmatrix}_R + \text{h.c.} \quad (8)$$

The Yukawa coupling y'' sign of top partner t' and t'' can be taken independently of the top quark Yukawa coupling y sign in order to generate destructive interferences between the top

quark and top parton contributions to $gg \rightarrow h$. After diagonalizing the mass matrix, we can get the mass eigenstates t , t_1 and t_2 as well as their couplings with the Higgs boson. The exotic quark $q_{5/3}$ has no the coupling to h at tree-level.

The triplet Higgs field Δ can mediate the interactions between the right-handed doublet quark field with $Y = 7/3$ and the left-handed doublet quark field with $Y = 1/3$. These interactions affect hardly the h production rates since the mixing angle between h and H is taken as very small in order to make h to be a purely SM-like Higgs. In the same way, the h couplings to the gauge bosons and light fermions equal to their SM values nearly.

III. $gg \rightarrow h$ AND $h \rightarrow \gamma\gamma$

In the SM, the main production processes of Higgs boson at the LHC include gluon-gluon fusion ($gg \rightarrow h$), vector-boson fusion (VBF) and associated production with W and Z bosons (Vh). Their cross sections are respectively [25]

$$\begin{aligned}\sigma(gg \rightarrow h) &= (15.3 \pm 2.6) \text{ pb}, & \sigma(pp \rightarrow jjh) &= 1.2 \text{ pb} \\ \sigma(pp \rightarrow Wh) &= 0.57 \text{ pb}, & \sigma(pp \rightarrow Zh) &= 0.32 \text{ pb}.\end{aligned}\tag{9}$$

Compared with SM, as a purely SM-like Higgs with 125 GeV mass, only $h \leftrightarrow gg$ and $h \rightarrow \gamma\gamma$ at one-loop are modified in the HTM with vector-like quark (HTMVQ), and the rates for other processes at tree-level are the same as the SM predictions.

A. The cross section of $gg \rightarrow h$

At the LHC the cross section of the single Higgs production via gluon-gluon fusion can be given,

$$\begin{aligned}\sigma(gg \rightarrow h) &= \tau_0 \int_{\tau_0}^1 \frac{dx}{x} f_g(x, \mu_F^2) f_g\left(\frac{\tau_0}{x}, \mu_F^2\right) \hat{\sigma}(gg \rightarrow h) \text{ with} \\ \hat{\sigma}(gg \rightarrow h) &= \Gamma(h \rightarrow gg) \frac{\pi^2}{8m_h^3},\end{aligned}\tag{10}$$

where $\tau_0 = \frac{m_h^2}{s}$ with \sqrt{s} being the center-of-mass energy of the LHC and $f_g(x, \mu_F^2)$ is the parton distributions of gluon. The Eq. (10) shows that the $\sigma(gg \rightarrow h)$ has a strong correlation with the decay width $\Gamma(h \rightarrow gg)$.

In the SM, $\Gamma(h \rightarrow gg)$ is dominated by top quark loop. The HTMVQ gives the corrections via the modified couplings $ht\bar{t}$ and the loops of top partner t_1 and t_2 . In the HTMVQ, $\Gamma(h \rightarrow gg)$ can be written as [26]

$$\Gamma(h \rightarrow gg) = \frac{\alpha_s^2 m_h^3}{128\pi^3 v^2} \left| y_t F_{1/2}(\tau_t) + y_{t_1} F_{1/2}(\tau_{t_1}) + y_{t_2} F_{1/2}(\tau_{t_2}) \right|^2, \quad (11)$$

where $\tau_f = \frac{4m_f^2}{m_h^2}$. The expression of $F_{1/2}$ is given in Eq. (14).

Parameter Set	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2
y	1.215	1.226	1.144	1.200	1.164	1.092	1.087	1.107	1.045	1.039
y'	-0.866	-1.124	-0.842	-1.386	-1.219	-0.753	-0.855	-1.009	-0.749	-0.983
\tilde{y}/y	0.705	0.898	0.798	0.818	0.380	0.791	0.540	0.890	0.568	0.568
y''/y'	-1.870	-1.546	-1.922	-1.169	-1.069	-1.944	-1.341	-1.148	-1.008	-1.026
m' (GeV)	507.3	669.7	609.5	735.0	552.3	715.7	554.0	711.8	547.8	960.0
m_{t_1} (GeV)	428.9	546.9	498.7	615.4	510.8	589.1	506.5	641.2	532.7	819.3
m_{t_2} (GeV)	1136	1193	1156	1193	1099	1158	1081.0	1115.3	1040	1164
y_t	0.362	0.380	0.567	0.466	0.604	0.765	0.754	0.728	0.852	0.899
y_{t_1}	-0.110	-0.171	-0.231	-0.151	-0.050	-0.261	-0.109	-0.118	-0.028	-0.165
y_{t_2}	0.199	0.241	0.213	0.234	0.157	0.204	0.131	0.165	0.072	0.161
R_{gg}	0.201	0.200	0.302	0.299	0.501	0.502	0.601	0.598	0.802	0.801
$\sigma_{\bar{t}_2 t_2 \rightarrow bW\bar{b}W}$ (pb)	0.0232	0.0041	0.0073	0.0016	0.0040	0.0025	0.0048	0.0013	0.0028	0.0002
LHC bound [27]	< 0.22	< 0.16	< 0.19	\times	< 0.18	< 0.14	< 0.14	\times	< 0.17	\times
$\sigma_{\bar{t}_2 t_2 \rightarrow tZ\bar{t}Z}$ (pb)	0.0321	0.0060	0.0118	0.0030	0.0153	0.0041	0.0173	0.0030	0.0166	0.0004
LHC bound [28]	< 0.29	< 0.28	< 0.30	\times	< 0.30	\times	< 0.3	\times	< 0.29	\times

TABLE I: The several points for $R_{gg} \simeq 0.2, 0.3, 0.5, 0.6$, and 0.8 . In addition to the parameters shown above, we take $m = 0$ GeV, $m'' = 1000$ GeV, $m_h = 125$ GeV and require $m_t \simeq 172.5$ GeV. $y_f = \frac{v}{m_f} g_{hf\bar{f}}$ with $g_{hf\bar{f}}$ being the coupling constant of $hf\bar{f}$. $\sigma_{\bar{t}_2 t_2 \rightarrow bW\bar{b}W}$ and $\sigma_{\bar{t}_2 t_2 \rightarrow tZ\bar{t}Z}$ represent $\sigma(pp \rightarrow t_1 \bar{t}_1) \times Br^2(t_1 \rightarrow bW)$ and $\sigma(pp \rightarrow t_1 \bar{t}_1) \times Br^2(t_1 \rightarrow tZ)$, respectively.

In Table I, we list several points for $R_{gg} \equiv \frac{\sigma(gg \rightarrow h)}{\sigma(gg \rightarrow h)_{SM}} \simeq 0.2, 0.3, 0.5, 0.6$ and 0.8 , respectively. The top partner t_1 mainly decays into th , tZ and bW . The CMS experiments at

the LHC have released the results of their searches for vector-like quark, and give the upper bounds of $\sigma(pp \rightarrow t_1 \bar{t}_1) \times Br^2(t_1 \rightarrow bW)$ and $\sigma(pp \rightarrow t_1 \bar{t}_1) \times Br^2(t_1 \rightarrow tZ)$. The HTMVQ predictions and LHC upper bounds for these rates are given in Table I. $\sigma(pp \rightarrow t_1 \bar{t}_1)$ is calculated with the HATHOR program [29] at NNLO. The cross section of $t_2 \bar{t}_2$ at the LHC can be severely suppressed by the large mass (over 1 TeV), which can be free from the constraints of LHC direct searches experiments. From Table I, we see that, being in agreement with the experimental constraints of LHC direct searches for t_1 and t_2 , the two vector-like top partners can suppress the cross section of $gg \rightarrow h$ sizably, and the cross section can be reduced by a factor of 0.2. The reduced top Yukawa coupling and the opposite sign between the Yukawa couplings of top and t_1 are responsible for the suppression of $\sigma(gg \rightarrow h)$.

B. the branching ratio of $h \rightarrow \gamma\gamma$

In the SM, the decay $h \rightarrow \gamma\gamma$ is dominated by the W loop which can interfere destructively with the subdominant top quark loop. In the HTMVQ, the singly charged scalar H^\pm , the doubly charged scalar $H^{\pm\pm}$, top partner t_1 and t_2 will give the additional contributions to the decay width $\Gamma(h \rightarrow \gamma\gamma)$, which can be expressed as [26]

$$\Gamma(h \rightarrow \gamma\gamma) = \frac{\alpha^2 m_h^3}{256 \pi^3 v^2} \left| F_1(\tau_W) + \sum_i N_{cf} Q_f^2 y_f F_{1/2}(\tau_f) + g_{H^\pm} F_0(\tau_{H^\pm}) + 4g_{H^{\pm\pm}} F_0(\tau_{H^{\pm\pm}}) \right|^2 \quad (12)$$

where

$$\begin{aligned} \tau_W &= \frac{4m_W^2}{m_h^2}, \quad \tau_{H^\pm} = \frac{4m_{H^\pm}^2}{m_h^2}, \quad \tau_{H^{\pm\pm}} = \frac{4m_{H^{\pm\pm}}^2}{m_h^2}, \\ g_{H^\pm} &= -\frac{v}{2m_{H^\pm}^2} g_{hH^+H^-}, \quad g_{H^{\pm\pm}} = -\frac{v}{2m_{H^{\pm\pm}}^2} g_{hH^{++}H^{--}}. \end{aligned} \quad (13)$$

N_{cf} , Q_f are the color factor and the electric charge respectively for fermion f running in the loop. The dimensionless loop factors for particles of spin given in the subscript are:

$$F_1 = 2 + 3\tau + 3\tau(2 - \tau)f(\tau), \quad F_{1/2} = -2\tau[1 + (1 - \tau)f(\tau)], \quad F_0 = \tau[1 - \tau f(\tau)], \quad (14)$$

with

$$f(\tau) = \begin{cases} [\sin^{-1}(1/\sqrt{\tau})]^2, & \tau \geq 1 \\ -\frac{1}{4}[\ln(\eta_+/\eta_-) - i\pi]^2, & \tau < 1 \end{cases} \quad (15)$$

where $\eta_\pm = 1 \pm \sqrt{1 - \tau}$.

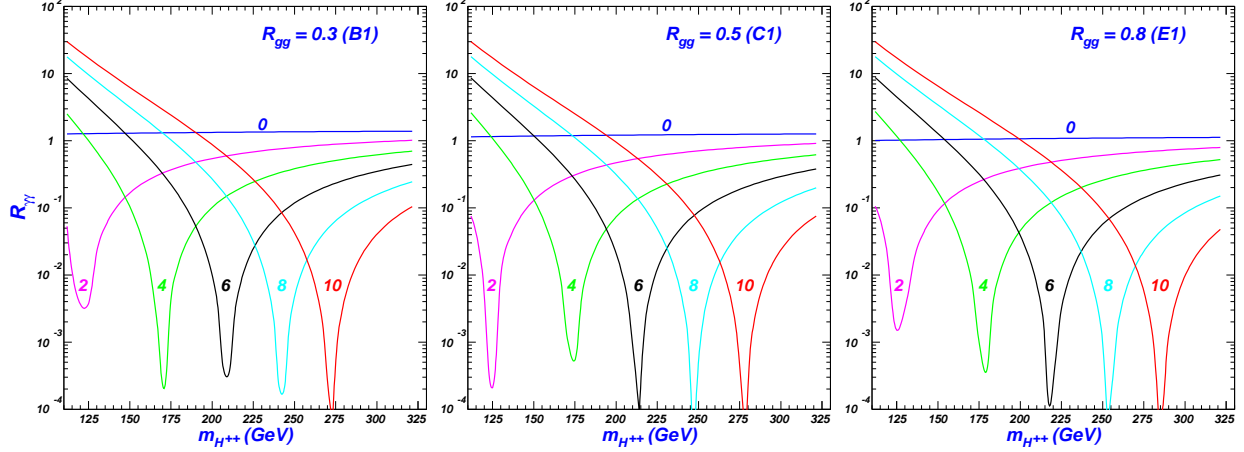


FIG. 1: $R_{\gamma\gamma}$ versus $m_{H^{\pm\pm}}$ for $R_{gg} = 0.3, 0.5$ and 0.8 , respectively. The numbers on the curves denote the coupling constant λ_1 .

Because $H^{\pm\pm}$ has an electric charge of ± 2 , the $H^{\pm\pm}$ contributions are enhanced by a relative factor 4 in the amplitude, which can further help $H^{\pm\pm}$ contributions dominate over the other particle contributions. The sign of the H^\pm and $H^{\pm\pm}$ contributions are respectively determined by g_{H^\pm} and $g_{H^{\pm\pm}}$ which are proportional to λ_1 and $\lambda_1 + \frac{\lambda_4}{2}$. For λ_1 and $\lambda_1 + \frac{\lambda_4}{2}$ are positive, the H^\pm and $H^{\pm\pm}$ contributions are constructive each other, but destructively with the contribution of W boson. The masses of H^\pm and $H^{\pm\pm}$ are respectively determined by λ_4 from Eq. (5), and vary in the range of $165 \text{ GeV} \sim 270 \text{ GeV}$ and $110 \text{ GeV} \sim 320 \text{ GeV}$ for the parameter space taken in Eq. (4). Recently, CMS presents the lower bound of 313 GeV on $H^{\pm\pm}$ mass from the searches for $H^{\pm\pm}$ decaying leptonically [30]. In this model, the limit can be reduced to 100 GeV since $H^{\pm\pm}$ will also decay into $W^\pm W^{\pm*}$ and $H^\pm W^{\pm*}$ [13]. LEP searches for both charged and neutral scalars give severe constraints on the possible existence of light scalars [31]. A conservative lower bound on m_{H^\pm} should be larger than 100 GeV due to the absence of non-SM events at LEP.

The widths of h decay modes at tree-level are the same both in the HTMVQ and SM. The branching ratio of $h \rightarrow \gamma\gamma$ in the HTMVQ normalized to the SM prediction can be defined as

$$R_{\gamma\gamma} = \frac{Br(h \rightarrow \gamma\gamma)}{Br(h \rightarrow \gamma\gamma)^{SM}} \simeq \frac{\Gamma(h \rightarrow \gamma\gamma)}{\Gamma(h \rightarrow \gamma\gamma)^{SM}}. \quad (16)$$

The top quark, top partner t_1 and t_2 contributions depend on the parameters shown in Table I. We take the three points B1, C1 and E1, and plot $R_{\gamma\gamma}$ versus $m_{H^{\pm\pm}}$ for $R_{gg} = 0.3, 0.5$ and 0.8 in Fig. 1, respectively. The H^\pm mass can be determined by $m_{H^{\pm\pm}}$ from the Eq. (5) and

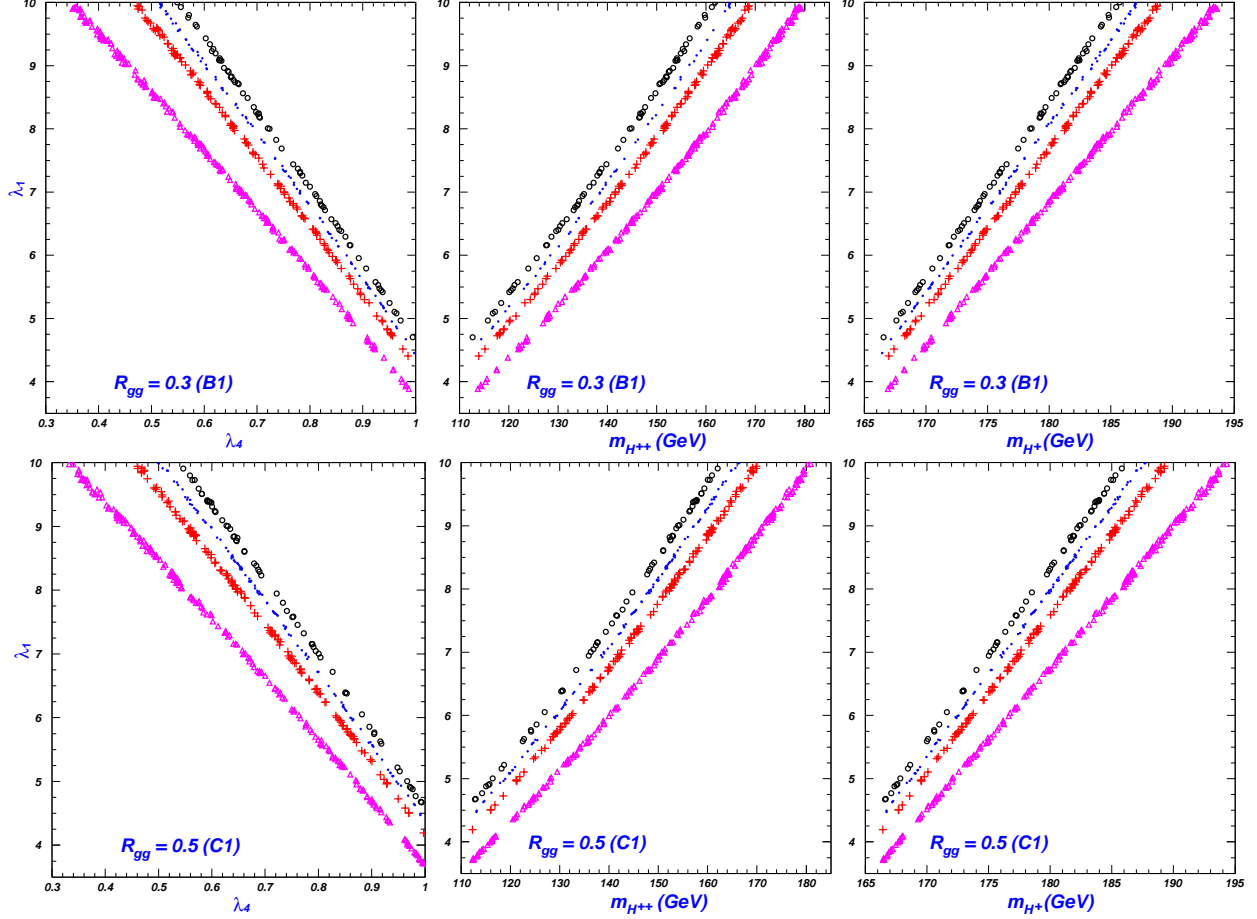


FIG. 2: For $R_{gg} = 0.3$ and 0.5 , scatter plots for (λ_1, λ_4) , $(\lambda_1, m_{H^{\pm\pm}})$ and $(\lambda_1, m_{H^{\pm}})$. $R_{\gamma\gamma} = 2.0$ for triangles (pink), $R_{\gamma\gamma} = 3.0$ for crosses (red), $R_{\gamma\gamma} = 3.5$ for bullets (blue) and $R_{\gamma\gamma} = 4.0$ for circles (black), respectively.

there are the small mass splitting between H^{\pm} and $H^{\pm\pm}$. For the small $m_{H^{\pm\pm}}$, the $H^{\pm\pm}$ and H^{\pm} contributions are very large and dominant over the other particle contributions, which leads that $R_{\gamma\gamma}$ reaches $\mathcal{O}(10^1)$ and is not sensitive to R_{gg} . With the increasing of $m_{H^{\pm\pm}}$, $H^{\pm\pm}$ and H^{\pm} contributions become small and have the severely destructive interference with other particle contributions, which leads $R_{\gamma\gamma}$ to be much smaller than 1. Because the coupling constants of $hH^{\pm\pm}H^{\mp\mp}$ and $hH^{\pm}H^{\mp}$ increase with λ_1 , the large λ_1 can enhance sizably the value of $R_{\gamma\gamma}$ for the small $m_{H^{\pm\pm}}$.

In Fig. 2, we scan the parameter space shown in Eq. (4), and give (λ_1, λ_4) , $(\lambda_1, m_{H^{\pm\pm}})$ and $(\lambda_1, m_{H^{\pm}})$ for which $R_{\gamma\gamma}$ equals to 2.0, 3.0, 3.5 and 4.0, respectively. We only take $R_{gg} = 0.3$ and 0.5 since $R_{\gamma\gamma}$ is not sensitive to R_{gg} , i.e. the contributions of top quark and top partners, as long as $R_{\gamma\gamma}$ is much larger than 1. We stress that λ_4 , $m_{H^{\pm\pm}}$ and $m_{H^{\pm}}$ are

dependent each other according to Eq. (5). Fig. 2 shows again $R_{\gamma\gamma}$ is not sensitive to R_{gg} when $R_{\gamma\gamma}$ is much larger than 1. $R_{\gamma\gamma} > 2.0$ favors $\lambda_1 > 4.0$, $\lambda_4 > 0.3$, $m_{H^{\pm\pm}} < 180$ GeV and $m_{H^\pm} < 195$ GeV, where the charged scalars masses can be in agreement with the current experimental data of LHC and LEP.

IV. THE HIGGS BOSON PRODUCTION RATES AT LHC AND TEVATRON

In Table II, we list the Higgs boson production rates normalized to the SM predictions for several values of R_{gg} and $R_{\gamma\gamma}$, and compare them with the corresponding measured values at the LHC and Tevatron. The measured $jj\gamma\gamma$ rate at CMS favors $R_{\gamma\gamma}$ in the range of 1.0 and 3.5 since the Higgs cross section in VBF production are the same both in the HTMVQ and SM. For $R_{gg} = 0.2$, the $\gamma\gamma$ rate is slightly enhanced. For $R_{gg} > 0.6$, the $\tau\bar{\tau}$ rate is outside the range of 1σ of CMS measured value. $R_{gg} = 0.5$ and $R_{\gamma\gamma} = 3.0$ can fit the measured Higgs rates at the LHC and Tevatron relatively well, for which the $\gamma\gamma$ and WW^* rates are respectively between the central values of CMS and ATLAS. Besides, the Higgs boson in the HTMVQ has two typical properties: (i) For the signals VV^* ($V = W, Z$), $\tau\bar{\tau}$ and $b\bar{b}$, the Higgs production rates normalized to their SM values are the same; (ii) $\sigma(pp \rightarrow Vh) \times Br(h \rightarrow b\bar{b})$ at the LHC and $\sigma(p\bar{p} \rightarrow Vh) \times Br(h \rightarrow b\bar{b})$ at the Tevatron are the same as their SM predictions, respectively.

The LHC diphoton Higgs signal can be well matched in many new physics models, such as the original HTM [13, 14], inert Higgs doublet model (IHDM) [17], Type-II two-Higgs doublet model (2HDMII) [19], and the model with universal suppression of Yukawa couplings of fermions (SCFM) [22]. For the HTM and IHDM, the new charged scalars can enhance the decay width of $h \rightarrow \gamma\gamma$ sizably. For the SCFM, the suppressions of $hb\bar{b}$ and $ht\bar{t}$ couplings can reduce the total Higgs decay width and Higgs production cross section via gluon-gluon fusion. For the 2HDMII, the new charged scalars and the modified Higgs couplings to SM particles can give the corrections to the LHC diphoton Higgs rate. However, compared to the SM predictions, for the LHC diphoton Higgs rate is enhanced, the Higgs production rate into WW^* at the LHC is hardly suppressed for the HTM, IHDM and 2HDMII. The Higgs production rate into $Vb\bar{b}$ at the Tevatron is always suppressed for the SCFM. These are disfavored by the recent LHC and Tevatron Higgs data. In the HTMVQ, only the processes $h \leftrightarrow gg$ and $h \rightarrow \gamma\gamma$ at one-loop are respectively suppressed and enhanced by the virtual

		LHC					Tevatron
R_{gg}	$R_{\gamma\gamma}$	$h \rightarrow \gamma\gamma$	$h \rightarrow WW^*$	$h \rightarrow ZZ^*$	$h \rightarrow \tau\bar{\tau}$	$jjh \rightarrow jj\gamma\gamma$	$Vb\bar{b}$
0.2	3.5	1.02	0.29	0.29	0.29	3.5	1.0
0.3	3.0	1.14	0.38	0.38	0.38	3.0	1.0
0.3	3.5	1.33	0.38	0.38	0.38	3.5	1.0
0.5	2.0	1.12	0.56	0.56	0.56	2.0	1.0
0.5	3.0	1.68	0.56	0.56	0.56	3.0	1.0
0.5	3.5	1.96	0.56	0.56	0.56	3.5	1.0
0.6	2.0	1.30	0.65	0.65	0.65	2.0	1.0
0.6	3.0	1.95	0.65	0.65	0.65	3.0	1.0
0.8	2.0	1.64	0.82	0.82	0.82	2.0	1.0
0.8	3.0	2.46	0.82	0.82	0.82	3.0	1.0
CMS		$1.56^{+0.43}_{-0.43}$	$0.6^{+0.5}_{-0.4}$	$0.7^{+0.5}_{-0.4}$	$-0.1^{+0.7}_{-1.7}$	$2.1^{+1.4}_{-1.1}$	\times
ATLAS		$1.9^{+0.5}_{-0.5}$	$0.5^{+0.6}_{-0.6}$	$1.3^{+0.6}_{-0.6}$	$0.5^{+1.5}_{-2.0}$	\times	\times
CDF-D0		\times	\times	\times	\times	\times	$1.8^{+0.7}_{-0.7}$

TABLE II: In HTMVQ, the Higgs boson production rates normalized to the SM predictions for several values of R_{gg} and $R_{\gamma\gamma}$. The corresponding measured values at the LHC and Tevatron are given in the last line.

contributions of the vector-like quarks and charged scalars, and the rates for other processes at tree-level are the same as the SM predictions, which is favored by the recent LHC and Tevatron Higgs data. Alternatively, one can introduce the charged and colored scalars or

vector bosons to suppress $h \leftrightarrow gg$ and enhance $h \rightarrow \gamma\gamma$, which is studied in ref. [32].

To get the minimal scenario with only additional vector-like quark multiplets including t' components able to strongly suppress the Higgs production via gluon-gluon fusion, an $SU(2)_L$ doublet is introduced to the HTMVQ, which contains the top partner t' and an exotic quark with the electric charge $5/3$. The exotic quark is harmless in the parameter fitting since it has no coupling to h at tree-level. The null results from experimental searches for fractionally charged heavy baryons or mesons suggest that the charges of any color triplet quarks should be quantized as $Q = \frac{2}{3} + \text{integer}$ [33], which implies $Q = 5/3$ is the smallest charge greater than the conventional $2/3$. The exotic quark with the electric charge $5/3$ is also predicted in the model with $SU(7)$ gauge group [34] and the model with a left-right custodial parity invariance of the electroweak symmetry breaking sector [35], respectively.

V. CONCLUSION

In the framework of Higgs triplet model, we introduce some vector-like quarks in order to explain the recent Higgs boson data released by LHC and Tevatron collaborations. Compared with the SM, only the processes $h \leftrightarrow gg$ and $h \rightarrow \gamma\gamma$ at one-loop are modified in this model. The cross section of $gg \rightarrow h$ can be sizably suppressed by top partners while $Br(h \rightarrow \gamma\gamma)$ can be more sizably enhanced by the singly and doubly charged scalars. Therefore, the model will enhance the Higgs production rates into $\gamma\gamma$ and $jj\gamma\gamma$, and those for WW^* , ZZ^* and $\tau\bar{\tau}$ at the LHC are reduced with respect to their SM values. The Higgs production rate into $Vb\bar{b}$ at the Tevatron is the same as the SM value. We find that the measured Higgs rates at the LHC and Tevatron favor $2.0 < R_{\gamma\gamma} < 3.5$ and disfavor $R_{gg} < 0.2$ or $R_{gg} > 0.6$. $R_{gg} = 0.5$ and $R_{\gamma\gamma} = 3.0$ can fit the measured Higgs rates at the LHC and Tevatron relatively well, for which the $\gamma\gamma$ and WW^* rates are respectively between the central values of CMS and ATLAS.

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